HYDRODYNAMIC STUDIES ON VERTICAL WALL, LOW-CRESTED RUBBLE MOUND AND SEMI-CIRCULAR BARRIER SYSTEM

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SYNOPSIS

1. INTRODUCTION

Coastal problems related to erosion and flooding are the outcome of the dominant wave climate in the area, in combination with currents, tides and storm surges. Further, an increasing hazard to the coastline is the development which alters the coast through the construction of buildings and infrastructures, and in so doing, interrupts the natural sediment deposition processes and wave regime. Additionally, the global climate change is causing a rise in sea-level and intensified storminess, which is yet another factor in beach erosion and flooding. Aftermath effects of recent devastating Tsunami on Indian coast alarmed the coastal engineers renew their designs for coastal management and protection systems. The creation of various coastal defence structures which protect coastlines through the reduction of the afore-mentioned problems is thus extremely important; an importance which has significantly increased during the last few decades along with amplified pressure on the coastal zone.

These conventional defensive structures serve the coastline in one of two ways. They can provide direct protection, by preventing the water from accessing the area in need of preservation, for example through seawalls, dikes or dams. The structures could also provide indirect protection by reducing the hydraulic load on the coastal area; as in the cases of groins or offshore breakwaters of various forms. The most commonly used coastal engineering tool is the sea wall. Today, vertical walls (seawalls) armor much of the developed shoreline. Many

have done their job admirably, protecting important establishments such as heavy industries, power plants, national highways, habitations etc., that otherwise could have probably tumbled in to the sea. Obviously, they block easy access to the beach and the view.

Essentially, a seawall acts as a layer between the vulnerable coastline and the ocean. Extreme wave action is supported by the seawall without eroding the coast, although the seawall itself will eventually break down and require repair or replacement. These walls also help to insulate communities from flooding, although high waves can still breach most seawalls.

Low-crested structures such as submerged breakwaters or artificial reefs present advantages compared to other types of coastal structures due to their low height and permeable nature. Firstly, due to the low freeboard (typically around still water level or below) they have a minimal visual impact on the coastline and as such are preferred, as they are much more aesthetically pleasing. Secondly, they are less expensive than conventional breakwaters as they require far less material to reach the required design height and are packed less densely to create the design permeability.

Thirdly, more permeable structures are better for the environment as they create a larger number of habitats for marine species within the structure; they also are less of an interruption to the natural (sediment) dynamics of the area. The dynamic state created by the LCS has direct consequences for the wave regime, the sediment transport and the overall hydrodynamics of the coastal cell.

2. MOTIVATION

Low-crested semi-circular porous and non-porous breakwaters are also used as defence barrier in the present study. Small wave force, good stability and low cost are main advantages of this type. Laboratory experimental data and practical observation show that: no overturning moment is induced for wave pressure in the structure surface passes through the center of the

circle. The lateral wave pressure is smaller than that on a vertical breakwater with the same height. As a result, the stability against sliding is increased while the construction cost is reduces. For this type being a hollow structure, it is fit for soft soil foundation because of small and almost uniformly distributed vertical force acting on foundation. Owing to prefabricated structure, rough sea areas can use it to withstand the large breakwater immediately after installation. The other characteristic is that it may be not the same time for the maximum horizontal wave force and the wave crest (trough) propagating over the breakwater top, and the maximum horizontal wave force generally generates at the time of the minimum sliding coefficient inducing.

The need for the protection of seawall to increase its lifespan has resulted in many force reduction techniques like, introduction of porosity, construction of re-entrant curve at the front face of the caisson, slotted wave screens in front of the vertical walls, providing curved face vertical walls or flared shape vertical wall, construction of horizontally composite caissons and construction of low-crested caissons etc. The introduction of porosity introduces weakness in the strength of the structure. The construction of horizontally composite structure in a dynamic environment is risky. Low-crested caisson breakwater attracts lesser forces but the overtopping of waves create significant disturbance on the lee side.

These drawbacks can be overcome by constructing an offshore low-crested breakwater in front of these structures to attenuate the incident wave energy. The offshore low-crested or submerged breakwater can be constructed after the construction of vertical walls without much risk for any berthing vessels and vertical walls. For existing weak or damaged primary protection structures, construction of a defence structure such as low-crested or submerged offshore breakwater is relatively an easy task.

Extensive theoretical and experimental studies have been conducted in the past to study the dynamic wave pressures and forces on vertical structures. Many authors conducted experimental study on the dynamic pressures on vertical walls due to regular waves in deep to shallow water conditions. Goda (1985) proposed design formulae for composite breakwater, which accounts for height of rubble foundation, to estimate breaking and non-breaking wave pressures and forces. These formulae were based on laboratory measurements as well as on theoretical considerations. Most of the design methods for vertical/steep walls have been developed for caisson breakwaters, which can be applied to seawalls or related shoreline structures, where the ratio of wave height to water depth conditions are in the appropriate range.

Kabelac (1963) reported investigations concerning the different shapes of submerged barriers. Tanaka (1976) performed monochromatic wave test that included both submerged and emerged crests with varying crest widths. Stability, overtopping and transmission of the rock armoured low-crested rubble mound breakwaters were tested for random waves in a wave flume by Allsop (1983). The damage measurements have been related to stability number and to free board. The stability of the low-crested and submerged breakwaters are described by Van der Meer and Pilarczyk (1990) by analyzing extensive data sets of the Ahrens (1987), Powell and Allsop (1985), Givler and Sorenson (1987) and Van der Meer (1988).

In the above studies, wave transmission on low-crested and submerged breakwaters is based on the assumption that wave travels as a progressive wave to the landside without any vertical wall or any other structures. Surface elevation measurements in these studies are for progressive waves on the leeside of the breakwater. A critical review of the literature shows that research in the area of wave interaction with vertical wall with an offshore barrier on its seaside is scarce, which is a significant gap in the knowledge on hydrodynamics of vertical reflective structure and porous defence barrier. Hence, the primary objective of the present research work is to carryout extensive systematic experimental studies on the hydrodynamic characteristics of vertical seawall defenced by an offshore low-crested rubble mound breakwater.

This type of protection can also be used as a *rehabilitation* measure in situations wherein it is required to reduce the wave forces to enhance the functional life of seawalls/caissons that are damaged by extreme wave forces. A theoretical analysis of the present problem is complex. Moreover, past literatures pertaining to the present problem are limited which is the main motivation for the present investigation with physical models. The results of the investigations can be used both for the design of seawalls and caisson type breakwaters with offshore defence barrier.

3 Importance of the Present Study

- The information on transmission over the low-crested breakwaters is useful in deciding the crest level of the vertical wall and the sedimentation characteristics in the pool if the system is designed for coastal protection and management. The above information is also useful if the system is designed for rehabilitation measures.
- Information on reflection from the vertical wall and the pool response characteristics useful if the system is contemplating for converting the existing damaged vertical wall as small fishing harbors or marinas. A quantitative assessment of the reduction in transmission and reflection will help in decision making for the investment on low-crested breakwaters.
- Knowledge of wave force acting on wall is important for designing the structural dimensions of the wall and the design of foundation for the wall. A qualitative assessment on force reduction due to the presence of the low-crested breakwater especially for an existing partly damaged structure will help for assessment of structural life extension in the presence of breakwater. For new seawalls with breakwater, the risk of damage is reduced due to reduced wave loads on seawalls.

4 Objectives and Scope

Based on the above critical review of literature, it is observed that the research in the area of wave interaction with vertical wall defenced by an offshore low-crested barrier is scarce, which is a significant gap in the knowledge on hydrodynamics of vertical wall and porous defence barrier. Hence, the primary objective of the present research work is to carryout

extensive experimental studies on the hydrodynamic characteristics of combined system of vertical wall and an offshore low-crested breakwater. The results of the investigations can be used both for the design of *rehabilitation* system and new seawalls with defence barrier on its seaside.

- To investigate experimentally the hydrodynamic performance of a system of vertical wall defenced by an offshore low-crested rubble mound and semi-circular breakwater by measuring
    - dynamic forces on the seawall and reflection from the wall
    - water surface oscillations in the pool between two structures.
- To investigate the effect of parameters such as
    - depth of submergence of an offshore low-crested breakwater
    - crest width of the breakwater
    - pool length (location of the low-crested breakwater from the wall) and
    - water depth

5. DESCRIPTION OF THE RESEARCH WORK

5.1 Experimental study

The experimental set-up of the present study is shown in Fig.1. The experimental investigations were carried out on a non-overtopping vertical wall (1180mmm length and 500m height) defenced by an offshore low-crested rubble mound breakwater with 2H:1V side and 1.5H:1V leeside slopes and; 1.50-2.00kg as armour and 0.20-0.50kg core stones. In the present investigation, the stability of the breakwater was not the focus of the experiments and hence, the formulae of Van der Meer (1987) were used for the design of the armour units. A low-crested semi-circular breakwater with 0, 5, 10 and 15 percentages of perforations was fabricated with GI sheet and MS angle frame. A block diagram showing all the test conditions adopted for the present study is shown in Fig.2. The experiments were conducted in a 45m long, 1.2 m wide and 1.2m deep wave flume in the Department of Civil Engineering, Andhra

University College of Engineering, Visakhapatnam, India. A vertical wall made of mild steel angles and foam plastic sheet was fixed over a two-component strain gauge type force balance. Using conductance type wave gauges, the incident and other wave elevations were measured. The measurements for regular wave tests were collected for 100 seconds at a sampling rate of 40Hz. A total of 488 sets of regular wave tests were performed. Time domain analysis of the regular wave time series has been carried out.

6. RESULTS AND DISCUSSION

In order to determine the non-dimensional parameters, which affect the forces on the vertical wall defenced by an offshore low-crested rubble mound breakwater, a dimensional analysis was performed. The non-dimensional force [F_{xwb}/ F_{xwob}] on the wall can be written as a function of wave steepness (kH), relative breakwater height (kd), relative free board (h_c/H) and the relative characteristic dimensions (kB), relative radius of semi-circular breakwater (R/L_{pl}). F_x is in-line force on the wall. B, R, h, h_c , and k are crest width, radius of semi-circular breakwater, height, crest free board of breakwater and wave height and number respectively. L_{pl} is the pool length.

6.1 Force due to Regular Waves

Forces measured on the wall are presented as a function of main influencing parameters kd, kH for different h/d values. Fig.3 describes the effect of the relative breakwater height on the non-dimensional force. It is clear from this figure that wave force reduces as the breakwater height increases and maximum reduction is when h/d=1.00. The non-dimensional force is small for steep waves. Steep waves dissipate its energy by breaking over the crest of the breakwater and thus resulting in a high reduction of force compared to flatter waves. Since a design wave is generally steep, its dissipation is more important. Fig.4 presents the variation of force ratio with non-dimensional frequency L_{pl}/L. It was observed that the distance between the barrier and the end wall, at which the wave force ratio becomes minimum, lies in the range of $\frac{1}{4}(n+1) < L_{pl}/L < \frac{1}{6}(2n+2)$ (n = 0,1,2,3…). Theoretical results of Yip et al., (2002) on the interaction of wave on vertical walls protected by a thin porous barrier also shows similar trend. For $L_{pl}/L < 0.25$, this figure shows shift in the force ratio peak (0.132) for h/d=1.00 and 1.16. For h/d=1.00, minimum force ratio is at 0.160 where as for h/d=0.66,0.83, 1.16 and 1.33 it is 0.111. For the submerged breakwater (h/d=0.66 and 0.83) and $L_{pl}/L < 0.25$ peak is at

0.198. For $L_{pl}/L > 0.25$ peak occurs at $L_{pl}/L = \frac{1}{6}(2n+2)$ for all five cases of h/d. The natural frequency of the pool between the two barriers is more than the frequency of the transmitted wave; this ensures that the pool will not experience the resonance.

7 Water surface elevations in the pool

Water surface elevations are measured at center of the pool length. Crest freeboard is one of the most important parameter for wave transmission. It is clear that for low-crested structures the lower the h_c the higher the wave overtopping will be and hence the wave transmission. Fig.5 shows the variation water surface elevation K_t with wave steepness for two crest width. For h/d=1.00, this figure shows significant reduction in water surface elevation especially for long period waves. For the parameter, h_c/H, all the influence of the wave height on the dimensionless parameter seems to be lost when h_c becomes zero. This results in large scatter in the values of water surface elevation for h_c/H =0.0. Variation of K_t with h_c/H is shown in Fig.6 for different B/h values. Ahrens (1987), reported that, transmission is significant over breakwater for h_c/H <1.0 and transmission through the breakwater for $h_c/H > 1.5$. For $-1 < h_c/H < 1.5$ both transmission through and over the breakwater are important.

8 CONCLUSIONS

The experimental studies have been carried out on vertical seawall defenced by an offshore low-crested rubble mound (LCRB) and semi-circular breakwaters for regular waves. Based on the results of the experimental study the following salient conclusions are obtained:

(a). Wave forces on the vertical wall

- Measured shoreward wave forces on the wall (without breakwater) are compared with Goda`s formula and observed that formula gives conservative force values for higher relative water depths and wave heights.
- Maximum reduction of force on wall was observed for h/d=1.00, *i.e.,* breakwater crest is at still water level, compared to submerged and emerged breakwaters. Steep waves do not contribute for maximum force on the wall defenced by breakwater.
- Maximum wave forces are observed to be reduced for the longer pool lengths than the shorter pool lengths.
- Reduction of wave forces on the wall was observed for the case of low-crested rubble mound breakwater with leeside vertical face compared to the conventional low-crested

rubble mound breakwater. This is an important result that can be considered for the design of wall defenced by LCRB leeside vertical face system. This allows (i) reduction in the volume of the material and (ii) facility for safe berthing of small fishing vessels and marinas.

- Non-dimensional force ratio of SCLB is less for zero submergence (h/d) in all its cases studied in the present investigation.
- Decrease in the non-dimensional force ratio with wave steepness and relative radius is observed for the SCLB.

(b). Water surface elevation in the pool located between wall and offshore breakwater

- Transmission coefficient (K_t) decreases with increase in wave height and, increases with increase in wave period.
- Transmission coefficient (K_t) for vertical faced LCRB is observed to be very much less for zero submergence (h/d=1.0) compared to conventional LCRB. The similar trend was observed for vertical faced LCRB with smaller submergence (h/d=0.80).
- The wave attenuation performance of the vertical faced LCRB may be much better than the other LCB`s. It would potentially reduce the navigational risk in the vicinity of the breakwater (in the pool) because it is a good energy dissipater.
- The average Transmission coefficient (K_t) was observed to be 0.36 for zero percent perforated low-crested semi-circular breakwater (SCLB) for the pool lengths and relative breakwater heights investigated in the present study.

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PROPOSED CONTENTS OF THE THESIS

CHAPTER 1 INTRODUCTION

CHAPTER 2 LITERATURE REVIEW

CHAPTER 3 EXPERIMENTAL INVESTIGATION

CHAPTER 4 RESULTS AND DISCUSSION

CHAPTER 5 SUMMARY AND CONCLUSIONS

List of publications based on this thesis

International conferences

1. Muni Reddy.M.G., Sannasiraj.S.A. and Sreenivas Reddy.K " Experimental study wave transmission and pool response of seawall defenced by low crested breakwater (paperID#010),2nd International conference on Port, Coastal and Offshore engineering, 12-13 Nov. 2012, Bandung, Indonesia.

2. Muni Reddy.M.G., Sannasiraj.S.A. and Sreenivas Reddy.K "Transmission and pool response of a low-crested breakwater and vertical seawall system", 8th *PIANC-COPEDEC-12*, 20 – 24 Feb, 2012, IIT Madras Chennai.

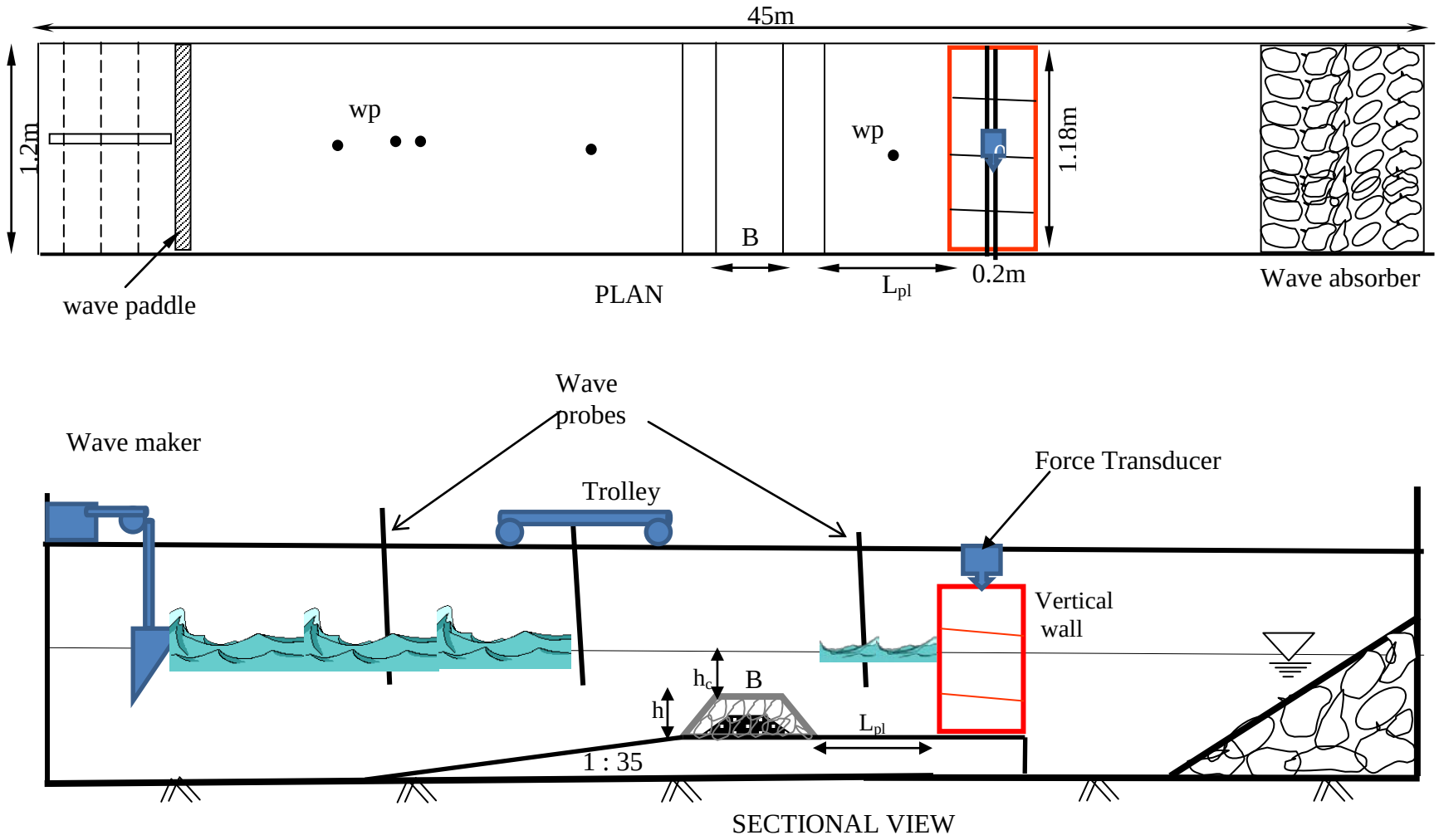

Fig.1. Schematic diagram of experimental set-up of vertical wall and low-crested rubble mound breakwater system

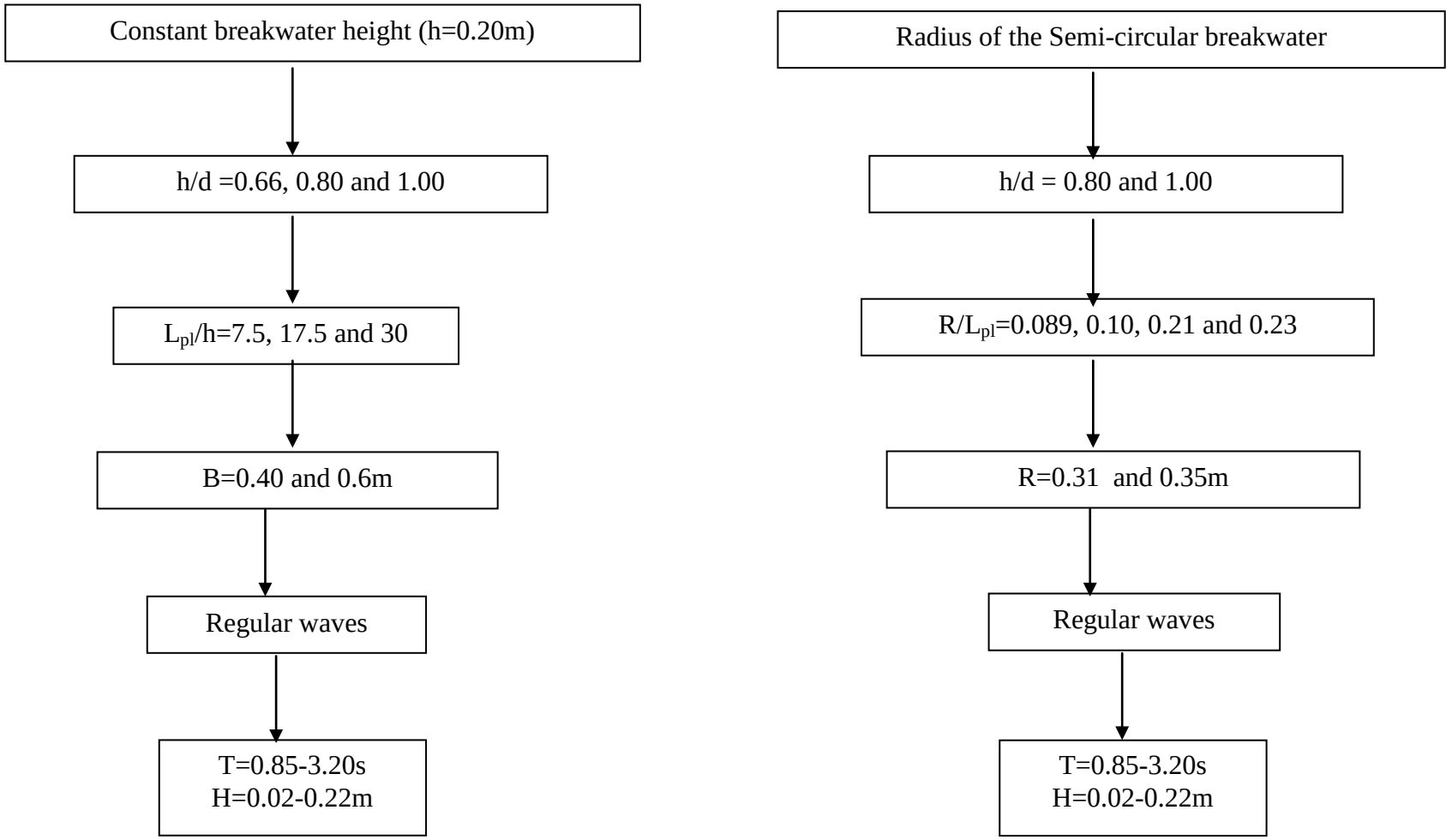

Fig.2. Block diagram for the model testing programme showing different test parameters adopted in the present study.

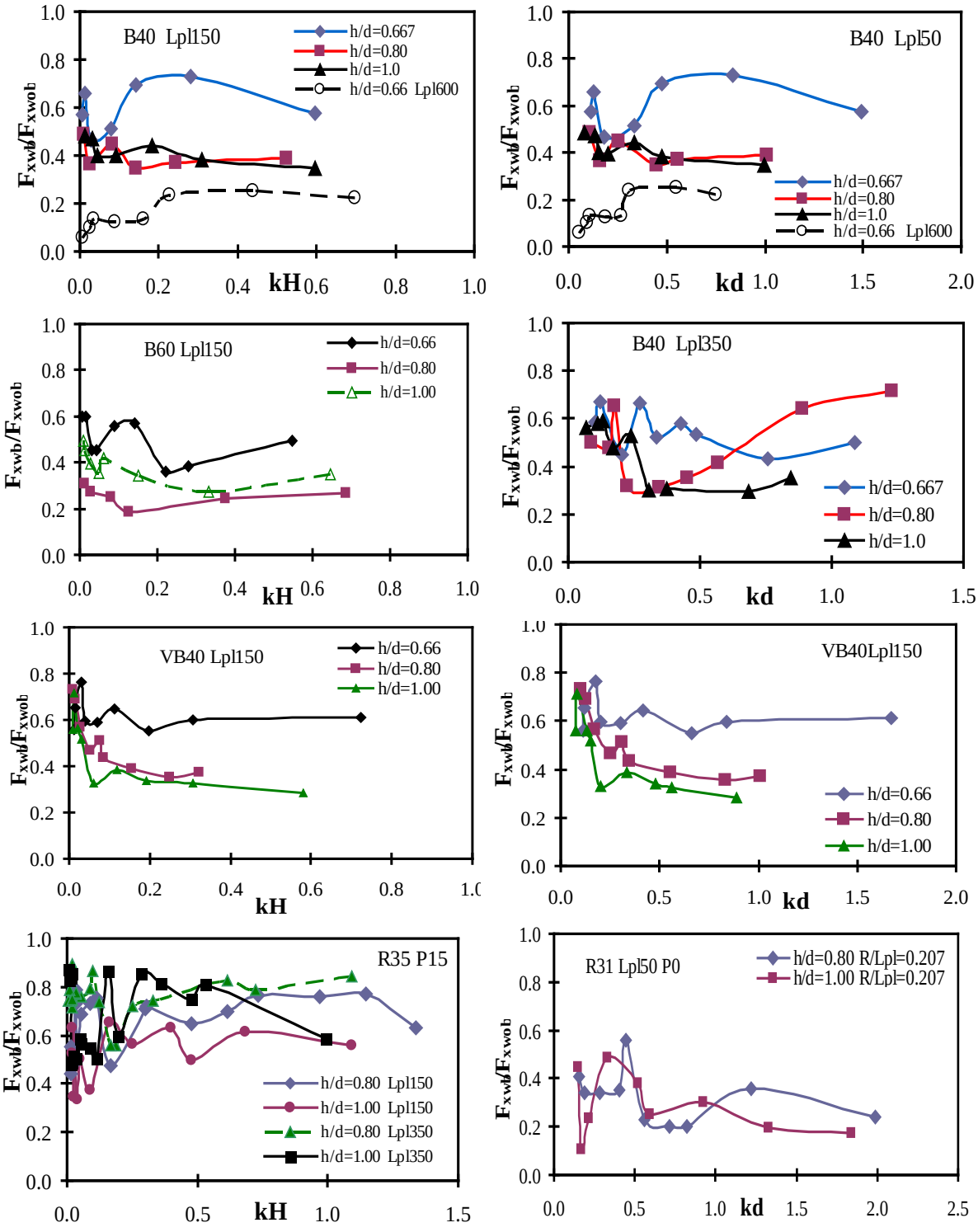

Fig.3. Variation of shoreward force ratio with wave steepness (kH) and relative water depth (kd) for different relative breakwater heights (h/d) under regular waves. VB is leeward vertical face rubble mound breakwater. R35P15 is semi-circular breakwater of radius 35 cm and 15% perforations.

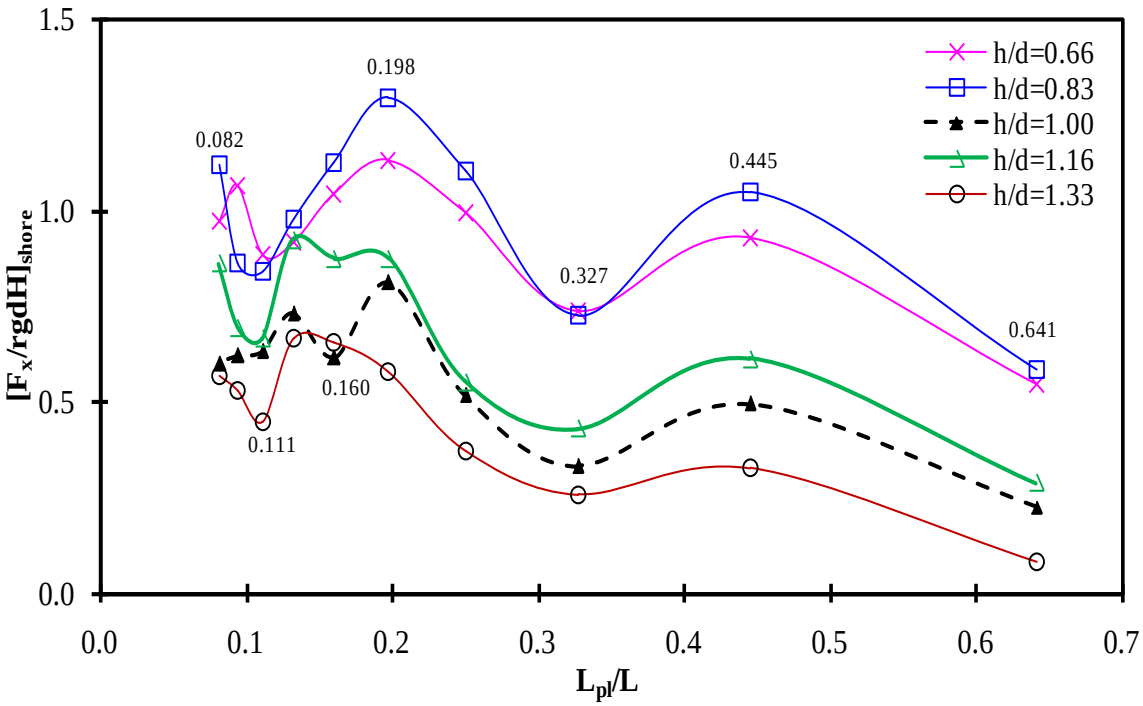

Fig. 4 Variation of Force ratio with non-dimensional pool length L_{pl}/L for $L_{pl}/d=3.33$ and $H/d=0.165$

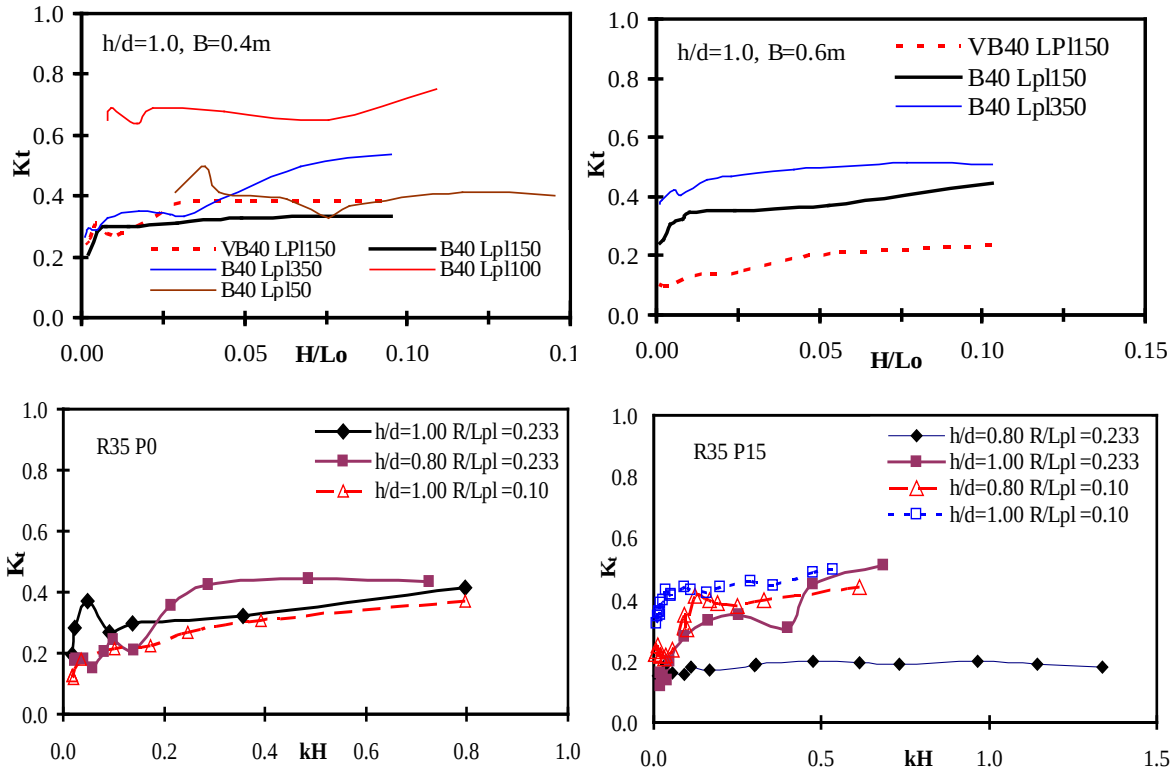

Fig.5. Variation of Transmission Coefficient with wave steepness under regular waves for different relative breakwater heights .

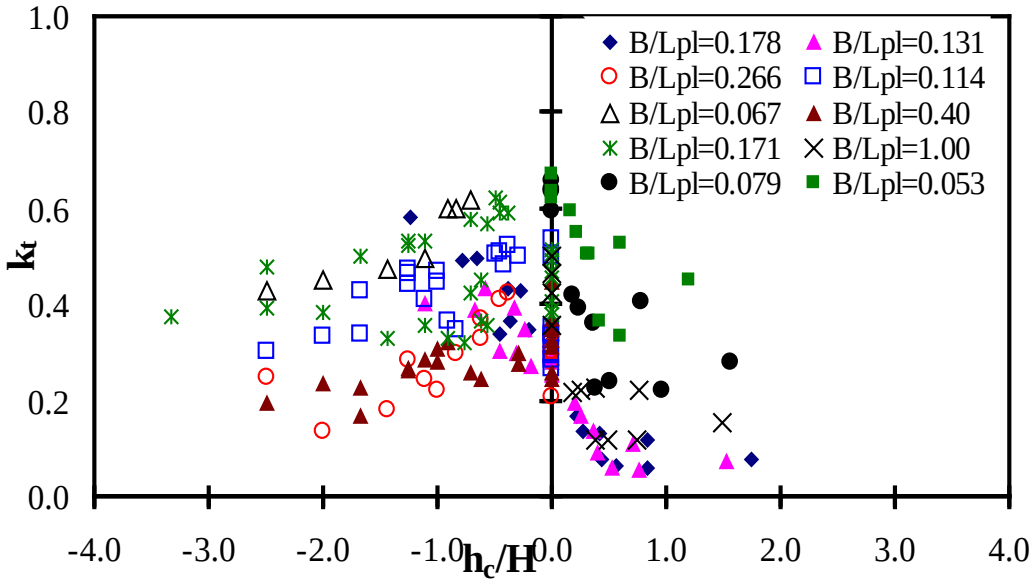

Fig 6. Variation of K_t with relative crest free board h_c/H under regular waves over (a) Rubble mound breakwater (b) Semi-Circular Low-crested Breakwater